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Linking between Renewable Energy, CO_2 Emissions, and Economic Growth: Challenges for Candidates and Potential Candidates for the EU Membership

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Abstract: This paper investigates the impact of renewable energy sources (RESs), CO_2 emissions, macroeconomics, and the political stability in a country on the Gross Domestic Product (GDP). The authors analyse the dynamics of RESs use, CO_2 emissions, and GDP development and also test the following hypotheses: (1) The country's economic growth is related to the energy consumption, in terms of both human resources and capital; (2) the share of the renewable energy consumption of the total energy consumption has a positive impact on the economic growth; and (3) the share of the renewable energy consumption of the total energy consumption is unrelated to the economic growth. To test the above hypotheses, the authors use the modified Cobb-Douglas production function, which also considers RES production volumes, CO_2 emissions, and economic growth. The study employs data between 1995 to 2015 from the candidate and potential candidate countries for the EU membership. The data are drawn from the World Bank and Eurostat. The analyses entail panel unit root tests, Pedroni panel cointegration tests, fully modified OLS (FMOLS), dynamic OLS (DOLS) panel cointegration techniques, and the Vector Error Correction model (VECM). The findings confirm the relationship between RESs, CO_2 emissions, and the GDP. For the EU countries, RESs as human resources and capital have an impact on the GDP. Moreover, the results reveal a correction retraction when the economic growth leads to an increase in renewable energy consumption. The investigation also finds that candidate and potential candidate countries for the EU membership should foster renewable energy development. The authors conclude that developing affordable and effective instruments and mechanisms to boost the RES implementation is necessary to decrease the anthropogenic impact on the environment (in particular, decreasing CO_2 emissions) without any attendant reduction in the economic growth.

Keywords: sustainability; renewable energy; CO_2 emissions; causal relationship; growth; stability; panel unit root tests

1. Introduction

According to scientists and experts forecasting into the near future, traditional energy resources (coal or crude oil) will soon be exhausted. Besides, the experts at the Paris Agreement Conference of

Parties (COP) declared that the fossil fuels age is over as such. On the other hand, the dependence on energy resources is still quite strong in most countries of the world, thus actualizing the necessity for developing and increasing the share of renewable energy in the overall energy balance. Besides, this development priority corresponds with the Sustainable Development Goals 2030, which have been accepted by the world's leading countries.

It should be noted that, according to the COP 21 report, the countries had agreed "to undertake rapid reductions thereafter, in accordance with the best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, on the basis of equity and in the context of sustainable development and efforts to eradicate poverty" [1].

Moreover, they agreed to support, develop, and enlarge the share of renewable energy and to develop economies with zero net emissions as soon as possible [2]. In practice, this means that the countries are going to increase their shares of renewable energy and are supposed to decrease their CO_2 emissions.

The EU countries are constantly increasing the share of renewable energy in their energy balance. According to the indicative goals, by 2020 the EU is going to generate 20% of their energy from renewable sources (Figure 1).

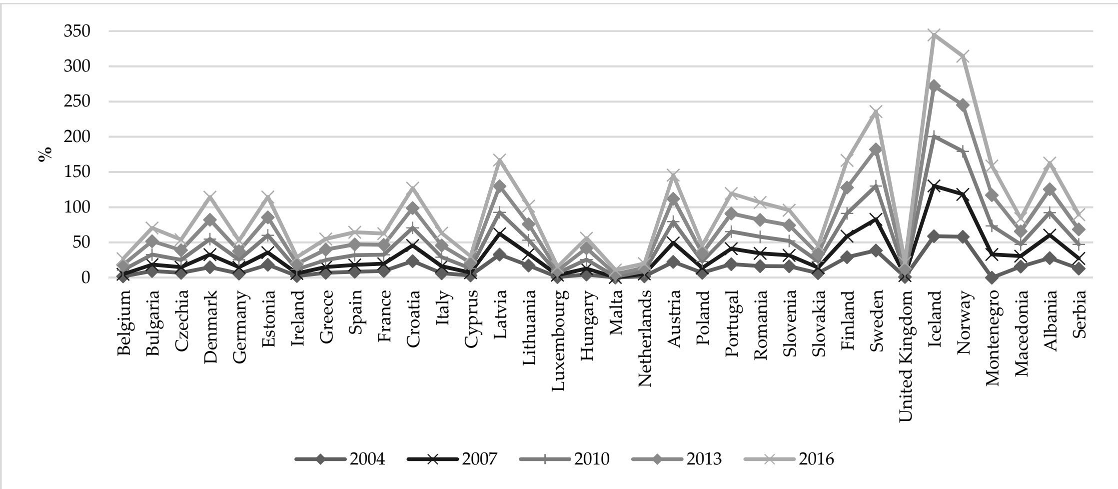

Figure 1. The shares of renewable energy in the gross final energy consumption (2004–2016) among the EU countries and candidates for the EU membership [3].

Thus, the results of the analysis show that most of the EU countries have already achieved the indicated goals before 2020 (Figure 1) and every year, the share of renewable energy in the gross final consumption is only growing. The leaders among the EU countries by the share of renewable energy in the gross final energy consumption are Iceland, Norway, Sweden, and Finland. Noteworthy, each EU country has its own goals on renewable energy: Germany has planned the share of 18%, Poland—15.5%, Lithuania—23%, Latvia—40%, Moldova—17%, and Estonia—25% [4,5]. A total of 11 countries of the EU had already achieved the set goals on renewable energy sources (RESs) in 2015, including Estonia and Lithuania.

Many scientists assume that increasing the share of renewable energy leads to a reduction of CO_2 emissions. The findings showed that, during 1961–1979, the average growth of CO_2 emissions in the European Union (EU) was 25.07% per year, which was 4,647,643.766 thousand kt at the end of 1979.

On the other hand, the development of the renewable energy sector always requires additional financial resources; this is no problem for the world leaders, including some of the EU members, but for most of the developing countries (including candidates and potential candidates for the EU membership), this is a big problem. Therefore, it is common for developing countries to boost their supporting policies and instruments using the best practices of the EU.

Overall context around the key problem. According to the world databases, the world's leading countries, such as China, the USA, India, Russia, and Japan, secured for themselves the first five places, in terms of the CO_2 emissions in the world, back in 2017 (see Table 1 for a fuller ranking) [6–8].

Table 1. Countries' shares in CO_2 emissions and world GDP [6–8].

Countries	GDP, bln $	% of World GDP	CO_2, kton (Gg) per Year	% of the World CO_2	CO_2 per 1$ of GDP
China	11,007.72	14.84	10,641,788.99	29.51	1034.39
USA	18,036.65	24.32	5,172,337.73	14.34	3487.14
India	2095.40	2.83	2,454,968.12	6.81	853.53
Japan	4383.08	5.91	1,252,889.87	3.47	3498.37
Germany	3363.45	4.54	777,905.50	2.16	4323.72
Republic of Korea	1377.87	1.86	617,284.88	1.71	2232.15
Canada	1550.54	2.09	555,400.90	1.54	2791.74
Saudi Arabia	646.00	0.87	505,565.10	1.40	1277.78
Indonesia	861.93	1.16	502,961.30	1.39	1713.72
Brazil	1774.72	2.39	486,229.08	1.35	3649.98
Mexico	1143.79	1.54	472,017.79	1.31	2423.20
Australia	1339.14	1.81	446,348.29	1.24	3000.21
South Africa	314.57	0.42	417,160.99	1.16	754.08
United Kingdom	2858.00	3.85	398,524.37	1.11	7171.46
Turkey	717.88	0.97	357,157.41	0.99	2009.98
Italy	1821.50	2.46	352,885.93	0.98	5161.72
France	2418.84	3.26	327,787.26	0.91	7379.28
Poland	477.07	0.64	294,879.37	0.82	1617.84
Ukraine	90.62	0.12	228,688.17	0.63	396.24
Lithuania	41.17	0.06	12,478.11	0.03	3299.44
World	**74,152.48**	**100**	**36,061,709.91**	**100**	**2056.27**

Thus, China generates only 14.84% of the world's GDP but, at the same time, it produces 29.51% of the world's CO_2 emissions. Similar situations are observed in the case of India and the Russian Federation. Their CO_2 emissions as a percentage are two times higher than their shares of the global GDP.

However, the case of Lithuania is quite the opposite. Their CO_2 emissions are half of their share in the world's GDP. It is necessary to emphasize that, in the USA and in most of the EU countries, their share in the world's GDP is higher than their share in the world's CO_2 emissions. In this context, it seems appropriate to understand the character of the link between a country's CO_2 emissions and its GDP as the main indicator of its economic growth.

As compared to other countries, Ukraine has the lowest level of the share of RESs in the final consumption, at only 6%. During the years of Ukraine's independence, the highest level of CO_2 emissions of about 630,929,352 thousand kt was registered back in 1992 [9].

The connection between energy production growth and the environmental load can be explained by the Environmental Kuznets curve [10]. It demonstrates the relationship of economic and ecological indicators and confirms that, in countries with rapidly developing economic indicators (GDP growth), the load on the environment is growing and, at the same time, the demand for cleaner and safer environments grows as the country's welfare increases.

Using the Environmental Kuznets curve on 17 OECD countries during 1977–2010 as an example, Bilgili F. and Ozturk Ilhan [11] came to a conclusion about the relationship between RES consumption volumes and CO_2 emissions. Thus, the authors in the papers [12–17] analysed the causes of CO_2 emissions and the ways of decreasing it. Besides, the scientists in the papers [18–22] proved that RESs play a key part in countries' energy security.

Similar conclusions were made after a scientist from Cyprus, Panayotou, studied 68 countries during the period 1980–1991 (1993) [23,24]. This scientist concluded that there was a relationship between economic growth and environmental degradation.

The authors of the papers of [25–29] proved the relationship between the ecological, social, and economic indicators which influence a country's GDP. The scientists proved that the link between social indicators [30–32], ecological indicators, which included the efficiency of RESs [13,18,22,31,33], and macroeconomic stability in low–middle-income countries existed [34,35].

At the same time, empirical estimation of the Environmental Kuznets curve for four countries with different income levels for the period of 1975–2014, fulfilled in the work of Azam and Khan [36], proves the absence of such dependencies for the countries with a high income. In the works [4,10,15,25,37–52], one of the proposed assumptions is a bidirectional or unidirectional relationship between economic growth (GDP) and RES growth.

For example, the studies of Al-mulali [37,38], Apergis and Payne [39–43], Dogan [45], and Menegaki [47] have resulted in mathematic confirmation of the bidirectional relationship between economic indicators of growth (GDP) and RES growth in the country.

Besides, the works of [52–59] study RES growth and associate it with the volumes of CO_2 emissions. Apergis [40], Bildirici [44], Ocal and Aslan [48], Ntanos, Chalikias, Arabatzis, G., Milioris, K., Chalikias, M., Lalou, P. [60,61] and others [62–65] have proven that there is a dependence between CO_2 emissions and RESs. The research by Menegaki [47] and Tugcu [66] confirms the independence (neutrality) of these indicators.

In order to confirm or contradict the above relationships, the researchers use an economic and mathematical system of data dynamics analysis, such as fully modified ordinary least squares (FMOLS), dynamic ordinary least squares (DOLS), or the augmented Dickey-Fuller (ADF) test (see Table 2).

Table 2. Summary of the empirical literature on GDP growth-energy consumption linking.

Author	Country	Period	Methodology	Variable	Results
Al-mulali et al. [37]	108	1980–2009	FMOLS	GDP, electricity consumption from renewable sources	79% feedback; 2% conservation; 19% neutral
Apergis and Payne [39–43]	80	1990–2007	FMOLS	GDP, total renewable electricity consumption, total non-renewable electricity consumption, real gross fixed capital formation, labour force	GDP <-> EC (RE, NRE)
Ben Jabli et al. [55,56]	24	1980–2010	FMOLS and DOLS	combustible renewables and waste consumption, GDP per capita, export per capita, price index	CO_2 <-> GDP (short-run); CO_2 <-> REC; GDP <-> REC
Cho et al. [63]	31	1990–2010	FMOLS, ADF, VECM	GDP, growth fixed capital formation, labour force, renewable electricity consumption	GDP<- >RE for developed GDP <- > RE for less-developed
Menegaki [47]	27	1997–2007	OLS-FMOLS	GDP per capita, gross inland energy consumption, final energy consumption, emissions in CO_2, employment rate	GDP and RE are neutral to each other
Sadorsky [62]	18	1994–2003	FMOLS, DOLS	per capita renewable energy, GDP per capita,	GDP <->RE
Tugcu et al. [66,67]	7 (G7)	1980–2009	ADF, PP	GDP, fixed capital formation, labour force, public and private tertiary education, patent applications, renewable energy consumption, non-renewable energy consumption	Different for countries
Zoundi [59]	25 (Africa)	1980–2012	FMOLS, DOLS, ADF	CO_2 emissions per capita, GDP per capita, renewable energy consumption per capita, population	CO_2 <-> GDP; RE <-> CO_2.

The main objective of the article is to reveal the connection between the country's GDP fluctuation and the RESs' volume growth, considering the political and macroeconomic situation in the country.

2. Methods

To analyse the relationship between RES and GDP in studies [45,46,66,67] authors used Cobb-Douglas production function:

$$Q = AL^{\alpha} \times K^{\beta} \quad (1)$$

where *Q*—total production (the monetary value of all goods produced in a year); *L*—labour input (the total number of person-hours worked in a year); *K*—capital input (the monetary worth of all machinery, equipment, and buildings); *A*—total factor productivity; α, β are the output elasticities of labour and capital, respectively.

Thus, the modified function (1) the authors presented as:

$$ln\ Y_{\rm i} = \phi + \alpha\ ln\ REC + \beta\ ln\ SREC + \gamma\ ln\ K + \delta\ ln\ L + \lambda\ ln\ T + \mu \quad (2)$$

where α, β, λ, γ—the output elasticities of labour and capital, corresponding; *L*—labour input (the total number of person-hours worked in a year); *K*—capital input (the monetary worth of all machinery, equipment, and buildings); *REC*—renewable energy consumption; *T*—trade openness; μ errors; ϕ—const; *SREC*—solar renewable energy respectively.

At the same time, it is necessary to take into account the level of the country's political and macroeconomic stability while studying the relationship between RES level and economic growth.

It is explained by the fact that power plants, which use RES technologies, have a long payback period. That is why in the investment assessment the macroeconomic and political stability factor is more significant because most programs on RES introduction is supported by the government. And GDP drop in countries, including EU member countries, during the financial an economic crisis, was caused by macroeconomic instability [9,34].

The authors have studied the EU countries, countries that are candidates to the EU, and potential candidate countries to EU membership (Albania, Macedonia, Bosnia and Herzegovina, Turkey, Georgia, and Ukraine). The findings of the cause and effect relationship between renewable energy, CO_2 emissions, and economic growth in EU countries, candidate EU countries, and potential candidate countries to the EU membership enables the comparison of a country's governance policy on decreasing the energy consumption and CO_2 emissions with the purpose of achieving long-term growth to be made.

Thus, the main hypotheses in the paper are: (1) The country's economic growth relates to the energy consumption from human recourses and capital; (2) increasing the share of renewable energy consumption of the total consumption has a positive impact on the economic growth; (3) the consumption of renewable energy is not a huge part of the total energy consumption and could not influence economic growth.

Of the findings in the paper [45,46], the model's parameters of the Cobb-Douglas production function (the GDP per capita in US$ (GDP), the gross fixed capital formation in US$ (*K*), and the total labour force (people from ages 15 and older who supply labour for the production of goods and services) (*L*)) along with the renewable energy consumption (the % of the total final energy consumption) (*RE*) and the CO_2 emissions (metric tonnes per capita) (CO_2) were chosen as the basis for the checking of the aforementioned hypotheses. Thus, the general function of the investigation is:

$$\mathrm{GDP}_{it} = f(K_{it},\ L_{it},\ RE_{it}, \mathrm{CO}_{2it}) \quad (3)$$

Modified function (3) can be demonstrated as panel cointegration equation:

$$\mathrm{lnGDP}_{it} = \ \phi\ +\ \alpha \mathrm{ln} RE_{it} + \beta\ \mathrm{lnCO}_{2it} + \gamma\ \mathrm{ln} K_{it} + \delta \mathrm{ln} L_{it} + \mu_{it} \quad (4)$$

where α, β, γ, and δ are the regression's parameters, which evaluate and explain the elastic output related to the *RE*, CO_2, *K*, and *L*; μ is the error term; $i = 1, \ldots, N$; and $t = 1, \ldots, T$.

During the first step of the econometric analysis, the panel unit root tests are provided for all of the chosen parameters of function (3), using the Im, Pesaran, and Shin's [68] (IPS); the Levin, Lin, and Chu [69] test (LLC); and the Fisher-type tests (ADF Fisher and PP Fisher) [69]. The basis of the aforementioned tests is to check the first hypothesis, which assumed the existing unit root in the panel of data in the time series and the alternative absence in the unit root. Therefore, using the general approach, the equitation IPS panel unit root tests could be presented as:

$$\Delta y_{i,t} = \alpha_i + \rho_i y_{i,t-1} + \sum_{j=1}^{p} \varphi_{ij} \Delta y_{i,t-1} + \varepsilon_{i,t-1} \tag{5}$$

where y takes the meaning of each of the parameters of Equitation (4); Δ is the first difference operator; ρ_i = 0 for all i, which is the null hypothesis; and ρ_i = 0 for at least one i, the alternative hypothesis which is non-existent for a unit root.

During the next step, the dates in the time series of the unit root in the panel are proven, using the methods which Pedroni [64] proposed to check the long-term correlation between these time series. In this case, the checking of the null hypothesis (no cointegration in the times series ($H0{:}p_i$ = 0)) could be done by using the system of the statistical tests, including the panel v-statistic, panel rho-statistic, panel PP-statistic, panel ADF-statistic, group rho-statistic, group PP–statistic, and group ADF-statistic. If the cointegration exists, the long-run equilibrium relationship will be estimated, using the fully modified OLS (FMOLS) and the dynamic OLS (DOLS) panel cointegration techniques. In the paper [70], the author indicated that, compared to the traditional aforementioned OLS method, the methods used provided more accurate results of the long-term relationship between the analysed cointegration vectors, in the condition of no homogeneity. During the last stage, the cause and effect relationship between renewable energy, CO_2 emissions, and economic growth is checked, using the Vector Error Correction model (VECM), which presents as follows:

$$\begin{aligned} \Delta \mathrm{lnGDP_{it}} = {} & \sum_{j=1}^{k} \beta_{1j} \Delta \mathrm{lnGDP_{i,t-j}} + \sum_{j=1}^{k} \gamma_{1j} \Delta \mathrm{lnRE_{i,t-j}} + \sum_{j=1}^{k} \delta_{1j} \Delta \mathrm{lnCO_{2i,t-j}} \\ & + \sum_{j=1}^{k} \theta_{1j} \Delta \mathrm{lnK_{i,t-j}} + \sum_{j=1}^{k} \varphi_{1j} \Delta \mathrm{lnL_{i,t-j}} + \omega_1 ECT_{i,\ t-1} + \Delta \mu_{1it} \end{aligned} \tag{6}$$

$$\begin{aligned} \Delta \mathrm{lnRE_{it}} = {} & \sum_{j=1}^{k} \beta_{2j} \Delta \mathrm{lnGDP_{i,t-j}} + \sum_{j=1}^{k} \gamma_{2j} \Delta \mathrm{lnRE_{i,t-j}} + \sum_{j=1}^{k} \delta_{2j} \Delta \mathrm{lnCO_{2i,t-j}} + \sum_{j=1}^{k} \theta_{2j} \Delta \mathrm{lnK_{i,t-j}} \\ & + \sum_{j=1}^{k} \varphi_{2j} \Delta \mathrm{lnL_{i,t-j}} + \omega_2 ECT_{i,\ t-1} + \Delta \mu_{2it} \end{aligned} \tag{7}$$

$$\begin{aligned} \Delta \mathrm{lnCO_{2it}} = {} & \sum_{j=1}^{k} \beta_{3j} \Delta \mathrm{lnGDP_{i,t-j}} + \sum_{j=1}^{k} \gamma_{3j} \Delta \mathrm{lnRE_{i,t-j}} + \sum_{j=1}^{k} \delta_{3j} \Delta \mathrm{lnCO_{2i,t-j}} \\ & + \sum_{j=1}^{k} \theta_{3j} \Delta \mathrm{lnK_{i,t-j}} + \sum_{j=1}^{k} \varphi_{3j} \Delta \mathrm{lnL_{i,t-j}} + \omega_3 ECT_{i,\ t-1} + \Delta \mu_{3it} \end{aligned} \tag{8}$$

where β, γ, δ, θ, and φ are the regression's parameters which would be estimated; ECT indicates the long-term effect; and ω is a parameter which characterises the deviation of the variables from the long-term equilibrium.

The annual dataset was obtained from the World Data Bank from 1995 to 2015. This period was chosen as, at the World Data Bank, the datasets of the shares of the RESs compared to the total energy consumption were presented only for the years 1995 to 2015. All of the variables are in natural logarithms.

3. Results

The results of the panel unit root tests for all of the chosen parameters of Formula (4), using the IPS test, LLC test, ADF Fisher, and PP Fisher tests, are presented in Table 3. The variables in the table are: The GDP per capita in US$ (GDP), the gross fixed capital formation in US$ (K), the total labour force (people from ages 15 and older who supply labour for the production of goods and services) (L), the renewable energy consumption (% of total final energy consumption) (RE), and the CO_2 emissions (metric tonnes per capita) (CO_2).

Table 3. Panel unit root results for GDP, K, L, RE, CO_2.

Variables	Test Statistics		(A) Level	(A) First Difference	(B) Level	(B) First Difference
GDP	LLC	Statistic	−2.34	−5.63	0.87	−3.50
		p-value	0.0097 *	0.00 *	0.81	0.0002 *
	IPS	Statistic	3.02	−7.63	3.25	−3.81
		p-value	1.00	0.00 *	1.00	0.0001 *
	ADF Fisher	Statistic	−3.81	13.98	−1.81	10.17
		p-value	1.00	0.00 *	0.96	0.00 *
	PP Fisher	Statistic	−3.81	13.98	−1.81	10.17
		p-value	1.00	0.00 *	0.96	0.00 *
K	LLC	Statistic	−2.84	−9.84	0.03	−3.51
		p-value	0.002 **	0.00 *	0.51	0.0002 *
	IPS	Statistic	1.93	−8.19	1.74	−3.76
		p-value	0.97	0.00 *	0.96	0.0001 *
	ADF Fisher	Statistic	−3.19	16.67	−1.37	10.07
		p-value	1.00	0.00 *	0.92	0.00 *
	PP Fisher	Statistic	−3.19	16.67	−1.37	10.07
		p-value	1.00	0.00 *	0.92	0.00 *
L	LLC	Statistic	−0.62	−5.90	−1.51	−1.83
		p-value	0.27	0.00 *	0.07 ***	0.03 **
	IPS	Statistic	4.06	−9.01	1.64	−4.32
		p-value	1.00	0.00 *	0.95	0.00 *
	ADF Fisher	Statistic	0.58	26.53	−0.12	19.86
		p-value	0.28	0.00 *	0.55	0.00 *
	PP Fisher	Statistic	0.58	26.53	−0.12	19.86
		p-value	0.28	0.00 *	0.55	0.00 *
RE	LLC	Statistic	8.98	−5.08	−0.90	−4.67
		p-value	1.00	0.00 *	0.18	0.00 *
	IPS	Statistic	13.37	−9.52	1.42	−3.59
		p-value	1.00	0.00 *	0.92	0.0002 *
	ADF Fisher	Statistic	−4.13	31.66	−1.30	9.18
		p-value	1.00	0.00 *	0.90	0.00 *
	PP Fisher	Statistic	−4.13	31.66	−1.30	9.18
		p-value	1.00	0.00 *	0.90	0.00 *
CO_2	LLC	Statistic	4.30	−7.46	0.66	−4.38
		p-value	1.00	0.00 *	0.75	0.00 *
	IPS	Statistic	4.65	−11.43	1.59	−4.33
		p-value	1.00	0.00 *	0.94	0.00 *
	ADF Fisher	Statistic	−2.23	56.48	−1.09	14.18
		p-value	0.99	0.00 *	0.86	0.00 *
	PP Fisher	Statistic	−2.23	56.48	−1.09	14.18
		p-value	0.99	0.00 *	0.86	0.00 *

*, **, and *** represents significance at the 1%, 5% and 10% levels, respectively, of significance (bold entries). (A)—EU countries, (B)—candidate and potential candidate countries to the EU membership.

For the EU countries only, using the LLC test, the indicators of the GDP and K were stationary at their levels; however, using the first difference, all of the indicators were integrated by one order, with all of the tests excluding the null hypothesis of the indicators being non-stationary. This proved the statement of Nelson C. R. and Plosser C. R. [71] correct, which referred to most macroeconomic indicators being non-stationary at this level, but becoming stationary after the first difference.

This similar behaviour demonstrates the indicators of Equation (4) for the candidate and potential candidate countries for EU membership. Thus, the null hypothesis of the unit roots for the panel data cannot be rejected at this level, excluding the indicator *L* for the test of the LLC; however, such a result is statistically significant at the level of 10%. As for the panel data for the EU countries, this hypothesis excludes series that are in the first differences.

All of the findings are statistically significant at the level of 1% and 5%. The findings allowed the test for panel cointegration between the GDP, *RE*, CO_2, *K*, and *L* to be established.

The findings proved the existence of cointegration between the variables for the EU countries at the significance levels of 1% and 5%, as 6 of the 11 results of the test (4 panels and 2 groups) excluded the null hypothesis, showing no cointegration of the time series. This allows the conclusion to be made that the multicounty panel variables are cointegrated and that, throughout this time series, long-term relationships exist. For the candidate and potential candidate countries for the EU membership, a cointegration relationship between the GDP, *RE*, CO_2, *K*, and *L* (which is indicated by the panel PP, panel ADF, and group ADF statistics) exists. All of the panel and group datasets are statistically significant at the level of 1% and 5%. In Table 4, the results of using the Pedroni panel cointegration tests are presented.

Table 4. Pedroni panel cointegration tests.

Dimension	Test Statistics	(A)		(B)	
		Statistics	Prob	Statistics	Prob
Within-dimension	panel v-statistic	−0.11	0.54	0.09	0.47
	panel rho-statistic	2.62	1.00	1.19	0.88
	panel PP-statistic	−2.01	(0.02) **	−2.73	(0.003) *
	panel ADF-statistic	−3.53	(0.0002) *	−2.16	(0.02) **
		(weighted statistic)			
	panel v-statistic	−0.51	0.70	−0.03	0.51
	panel rho-statistic	2.29	0.99	0.83	0.80
	panel PP-statistic	−2.61	(0.004) *	−3.02	(0.004) *
	panel ADF-statistic	−2.82	(0.002) *	−1.86	(0.03) **
Between-dimension	group rho-statistic	3.97	1.00	1.86	0.97
	group PP–statistic	−3.26	(0.0006) *	−0.22	0.41
	group ADF-statistic	−1.84	(0.03) **	−2.13	(0.02) **

* and ** represent significance at the 1% and 5% levels. (A)—EU countries, (B)—candidate and potential candidate countries to the EU membership.

Considering that the variables are cointegrated, the next step is the estimation of the long-run equilibrium relationship. In Table 5, the findings of the use of the FMOLS and DOLS panel cointegration techniques are presented.

Table 5. Estimation of the cointegrating relationship.

Variables		FMOLS				DOLS			
		(A)		(B)		(A)		(B)	
Dependent	**Independent**	**Long-Run Coefficient**	**Prob**	**Long-Run Coefficient**	**Prob**	**Long-Run Coefficient**	**Prob**	**Long-Run Coefficient**	**Prob**
GDP	**RE**	15.76	(0.00) *	−89.56	(0.082) ***	16.56	(0.00) *	−33.70	(0.0003) *
	CO_2	21.80	(0.006) *	59.37	0.83	53.67	(0.00) *	−21.64	(0.00) *
	K	0.00	(0.0001) *	0.00	(0.00) *	0.00	(0.0004) *	0.00	(0.004) *
	L	0.00	0.72	0.00	(0.04) **	0.00	0.77	0.00	0.41
R-squared adj.		0.86		0.83		0.99		0.99	
0RE	**GDP**	0.0002	(0.00) *	−0.0004	0.42	0.0002	(0.00) *	−0.003	(0.0002) *
	CO_2	−2.15	(0.00) *	−2.19	(0.004) *	−1.62	(0.00) *	−6.31	(0.0001) *
	K	0.00	0.23	0.00	0.88	0.00	0.75	0.00	(0.07) ***
	L	0.00	0.25	0.00	0.79	0.00	0.72	0.00	0.78
R-squared adj.		0.9587		0.90		0.9946		0.9949	
CO_2	**GDP**	9.59×10^{-6}	0.18	8.05×10^{-5}	0.47	2.90×10^{-5}	(0.034) **	−0.0004	(0.00) *
	RE	−0.16	(0.00) *	−0.089	(0.0034) *	−0.09	(0.001) *	−0.11	(0.00) *
	K	7.30×10^{-13}	0.63	-8.74×10^{-12}	0.27	-9.74×10^{-13}	0.78	1.14×10^{-11}	(0.05) **
	L	-1.63×10^{-7}	0.10	2.77×10^{-7}	0.15	-1.45×10^{-7}	0.52	0.62	0.54
R-squared adj.		0.96		0.86		0.99		0.99	

* and ** represents significance at the 1% and 5% levels. (A)—EU countries, (B)—candidate and potential candidate countries to the EU membership.

These two approaches demonstrate the similar impact that the *RE*, CO_2, and *K* had on the GDP of the EU countries, in terms of the sign, long-term elastic, and statistical significance. Thus, the findings are statistically significant at 1% for all three of the parameters. Increasing the *RE* by 1% provokes an increase in the GDP by 15.76% (for FMOLS) and by 16.56% (for DOLS), while increasing the CO_2 by 1% leads to an increase in the GDP by 21.80% (for FMOLS) and by 53.67% (for DOLS). At the same time, the increasing of the GDP by 1% for FMOLS provokes an increase of the *RE* by 0.0002% and of the CO_2 by 9.59×10^{-6}%, but for DOLS, the *RE* is reduced by—0.0002% and the CO_2 by—2.90×10^{-5}%. The impact of the CO_2 on the *RE* has a negative impact on the FMOLS and DOLS panel cointegration techniques.

However, for the candidate and potential candidate countries for the EU membership, the impact of the *RE* and CO_2 on the GDP has another character. From a long-term perspective, the findings of the FMOLS proved that a 1% increase in the *RE* leads to a decrease in the output by 89.56% (the results are statistically significant at a level of 10%), but such a level of statistical significance did not enable the null hypothesis to be refused. Thus, from this investigation, such results were not taken into account. For DOLS, the increasing of the *RE* leads to a decrease in the output by 33.70% (the results are statistically significant at a level of 1%). The impact of the CO_2 on the GDP had a statistically significant effect at the level of 1%. For that countries' group for the DOLS approach, the GDP will decrease by 21.64% if the CO_2 increases by 1%. The negative impact on the *RE* and CO_2, with the statistical significance at a level of 1% according to the DOLS method, caused an increase of the GDP.

The results of the short-run Granger causality tests for the VECM, based on Equations (6)–(8), are shown in Table 6. For the EU countries, the bidirectional short-run causality between the CO_2 and the GDP exists at the 1% significance level. There is also a unidirectional short-run causality, running from the GDP and the RE at a significance level of 1%. Besides, the bidirectional causality between the RE and CO_2 exists at 1% and 5% levels. The long-run test results (Table 6) proved that the error correction term is negative and is statistically significant at the 10% level only for Equitation (6).

Table 6. Panel Vector Error Correction Estimate.

Dependent Variables	Short Run					Long Run
	D(GDP)	**D(RE)**	**D(CO_2)**	**D(K)**	**D(L)**	**ECM_{t_1}**
D(GDP)	0.18 (0.001) *	7.10×10^{-5} (0.01) *	-3.43×10^{-5} (0.001) *	−112,135.7 (0.77)	1.03 (0.66)	−0.002 (0.09) ***
D(RE)	−40.02 (0.68)	−0.039 (0.40)	−0.050940 (0.007) *	1.96×10^{-8} (0.78)	286.68929 (0.95)	2.77×10^{-7} (0.65)
D(CO_2)	726.30 (0.002) *	−0.22 (0.05) **	−0.089886 (0.05) ***	3.15×10^{9} (0.06) ***	5055.37 (0.63)	-1.59×10^{-7} (0.52)
D(K)	-9.19×10^{-10} (0.90)	-3.66×10^{-12} (0.29)	7.47×10^{-13} (0.59)	0.20 (0.0001) *	1.19×10^{-6} (0.0002) *	22613.53 (0.0136) **
D(L)	0.0017 (0.05) **	-4.81×10^{-7} (0.25)	2.20×10^{-8} (0.90)	21242.29 (0.0009) *	−0.434828 (0.0004) *	0.29 (0.00) *

*, **, and *** represents significance at the 1%, 5% and 10% levels. Lag lengths selected is 1 based on the Schwarz Information Criterion.

Therefore, the findings allow the conclusion to be made that the long-run causality, running from the *RE*, CO_2, *K*, and *L* to the GDP, exists for EU countries. However, the error correction terms for Equitations (7) and (8) are statistically significant, which allows the hypothesis about bidirectional causation between the GDP and the *RE* and CO_2 to be excluded.

4. Discussion

In order to achieve the sustainable development goals by 2030, the share of renewable energy in the total energy budget of the world should be increased. The obtained results of the analysis above concerning the EU activities in this direction show that most of the EU countries have already achieved the indicated goals related to their shares of renewable energy in the gross final energy consumption, long before 2020.

We should not forget here that developing the renewable energy sector always requires additional financing. Thus, most of the EU countries, as developed nations, have sufficient financing to support renewable energy development. Quite the opposite situation is observed in developing countries, including the countries which are going to join the EU. The majority of these countries do not have sufficient financing and thus, should attract additional green investments from other countries. Within this research, the hypothesis on the link between the countries' economic growth, capital, human resources, renewable energy consumption, and CO_2 emissions has been tested.

The Pedroni panel cointegration tests proved the cointegration between these variables for the EU countries, at the significance levels of 1% and 5%, as 6 forms of the 11 results of the test (4 panels and 2 groups) excluded the null hypothesis about no cointegration of the time series. In addition, for both candidates and potential candidates for the EU membership, a cointegration relationship between the GDP, RE, CO_2, K, and L exists. All panel and group datasets demonstrate statistical significance at the levels of 1% and 5%.

The use of FMOLS and DOLS panel cointegration techniques demonstrate similar impact results and prove that *RE*, CO2, and *K* have impacts on the GDP of the EU countries. Thus, the findings are statistically significant at the level of 1% for all three of the parameters. The increase of the *RE* by 1% provokes the increase in the GDP by 15.76% (for FMOLS) and by 16.56% (for DOLS), while the increase in CO_2 by 1% leads to a GDP increase by 21.8% (for FMOLS) and by 53.67% (for DOLS).

The findings were similar as in the papers [11,46,72–75], which proved the effective policy of regulation among EU countries and showed the positive relationship between renewable energy, energy efficiency improvement, CO_2 emissions, and economic growth.

The obtained results allow the conclusion to be made that, for EU countries, renewable energy has a huge impact on economic growth, as the correction retraction with economic growth leads to an increase in the energy consumption from renewable energy. However, the candidate and the potential candidate countries for EU membership should provide a more reactive policy on developing renewable energy consumption. In this case, the EU experience allows the conclusion to be made that, for the first step, supportive financial and non-financial mechanisms should be developed and implemented by the candidate and the potential candidate countries for EU membership. The consolidated data of effective renewable energy support policies are shown in Figure 2 [50,60,61,65].

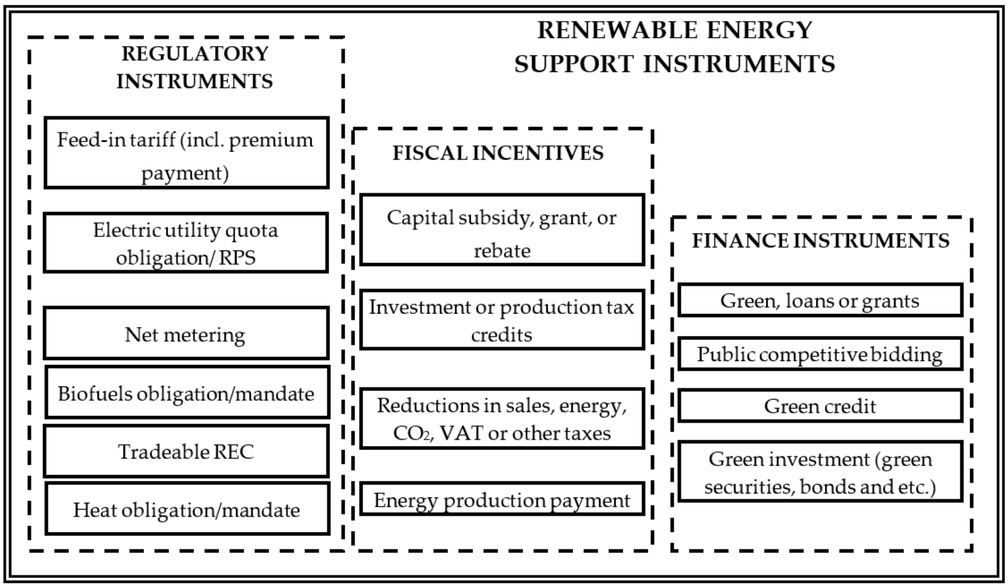

Figure 2. Systematization of incentive mechanisms and instruments. Compiled by the authors on the basis [50,60,61,65,72,73].

The ongoing economic situation among the candidate and the potential candidate countries for the EU membership necessitates finding and implementing a modern incentive mechanism which will take into account the specifics of economic functioning. A proven and effective mechanism to encourage the development of renewable energy in EU countries is the use of feed-in tariffs for electricity produced from renewable energy sources. Besides, these measures in Germany, Spain, and Denmark had an impact on the development of large-scale projects using renewable energy [61].

It was noticed that the tendency of economic growth and financial resources among the candidates for the EU were required to attract the additional green investment for financing green projects, which can provide an increasing share of the renewable energy consumption in the total energy consumption.

5. Conclusions

The findings proved that, for the EU countries, the long-run causality running from the *RE*, CO_2, *K*, and *L* to the GDP indeed exists. Thus, renewable energy is a truly significant factor influencing economic growth through human resources and capital. However, for candidates and potential candidates for the EU membership, the impact of the *RE* and CO_2 on the GDP has another character.

The obtained results also prove that renewable energy has a huge impact on economic growth in the EU region. The correction retraction is that economic growth leads to an increase in energy consumption on the side of renewable energy. This hypothesis was not confirmed for the candidates and potential candidates for the EU membership. The final general conclusion would be that countries should boost their supporting policies to promote the quicker development of the renewable energy sector. This will provide double dividends, such as GDP growth and GHG emission reduction, in the long term.

In further investigations, it is necessary to produce a scenario analysis of achieving the indicated targets of the RES and declining the CO_2 emissions among the EU if the candidates and potential candidates will join the EU. Also, the effect of the UK's withdrawal from the EU should be assessed and the effects of different influencing factors on the GDP growth and the future directions in the EU should be investigated. With the purpose of achieving convergence under the EU integration process, it is necessary to investigate the routes for spreading the RES in the total energy consumption among the candidates and potential candidates for the EU membership.

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